NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE 4111

INVESTIGATION OF THE COMPRESSIVE STRENGTH AND CREEP OF 7075-T6 ALUMINUM-ALLOY PLATES AT ELEVATED TEMPERATURES

By William D. Deveikis

Langley Aeronautical Laboratory
Langley Field, Va.

Washington
November 1957

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE 4111

INVESTIGATION OF THE COMPRESSIVE STRENGTH AND CREEP OF 7075-T6 ALUMINUM-ALLOY PLATES AT ELEVATED TEMPERATURES

By William D. Deveikis

SUMMARY

Elevated-temperature compressive-strength test results from room temperature to 600° F and creep test results from 350° F to 500° F are presented for V-groove edge-supported plates of 7075-T6 aluminum alloy. The test data are compared with calculations obtained from procedures for estimating maximum strength from material stress-strain curves and creep-failure stresses from isochronous stress-strain curves. The strength and creep results from this investigation are also compared with similar results from 2024-T3 aluminum-alloy plates.

INTRODUCTION

The behavior of structural elements at elevated temperatures is an important consideration in the structural design of high-speed aircraft. Changes in material properties and time-dependent deformations are effects associated with elevated temperatures which have given rise to the need for adequate procedures for determining both short-time strength at these temperatures and stresses that will cause failure due to creep. Several investigators have shown that the procedures commonly used for correlating strength with material properties at room temperature may also be used to effect correlation at elevated temperatures if the material stress-strain curve at the applicable temperature and exposure time is known (refs. 1 to 5). These procedures have also been found useful in the estimation of creep-failure stresses by substituting isochronous stress-strain curves for the material stress-strain curve (refs. 4 to 8).

In the present paper, an analysis is undertaken to determine the applicability of a procedure for correlating plate strength with material properties (given in ref. 2) to 7075-T6 aluminum-alloy plates tested at elevated temperatures under both short-time and creep loading conditions.

In addition, the data in this paper permit a direct comparison with the strength and creep results for 2024-T3 aluminum-alloy plates given in reference 4.

SYMBOLS

A, σ_o, K	material creep constants
b	width, in.
E_s	secant modulus, ksi
t	thickness, in.
T	temperature, $^{\circ}F$
T_R	absolute temperature, $^{\circ}R$
R.T.	room temperature
ϵ	strain
$\bar{\epsilon}$	unit shortening
$\bar{\epsilon}_f$	unit shortening at maximum (failing) load
σ	stress, ksi
$\bar{\sigma}$	average stress, ksi
σ_{cy}	0.2-percent-offset compressive yield stress, ksi
$\bar{\sigma}_f$	average stress at maximum (failing) load, ksi
τ	time, hr
τ_f	failure time, hr

SPECIMENS, EQUIPMENT, AND PROCEDURES

In the present investigation, compressive-strength tests were performed on plates for width-thickness ratios ranging from 15 to 60 at temperatures up to 600° F and plate creep tests were performed at temperatures from 350° F to 500° F. In addition, material properties were obtained from compressive stress-strain tests at temperatures up to 600° F. The plate specimens were 20.00 inches long and the compressive stress-strain specimens were 2.52 inches long and 1.00 inch wide. All specimens were machined from a 1/16-inch-thick 7075-T6 aluminum-alloy sheet with the specimen length oriented parallel to the grain direction of the sheet.

The testing and recording equipment is shown in figure 1. This equipment was also used in the investigation of creep of 2024-T3 aluminum-alloy plates reported in reference 4. In the figure the furnace has been removed to reveal the test fixtures and plate specimen. Load was applied with the hydraulic testing machine in the plate strength tests, and the dead-weight apparatus was used to maintain constant load on the specimen during the creep tests. Shortening of the plates during both the compressive-strength and creep tests was determined by measuring the relative motion between the top and bottom loading surfaces with linear variable differential transformers. The specimen temperature was measured with iron-constantan thermocouples and maintained within ±5° F of test temperature.

Support for the side edges of the plate specimens was provided by V-groove edge fixtures (fig. 2). A small clamping force was required to keep the specimen alined in the grooves. When the test temperature was attained and stabilized, adjustments were made to the clamping bolts of the fixture to achieve as closely as possible the clamping force used in the room-temperature strength tests. In a creep test, if the plate specimen did not collapse within an 8-hour day, the load was removed, and the specimen was cooled to room temperature. The test was then resumed the following day as soon as test temperature was attained. This procedure was continued until the plate specimen collapsed.

All plate and stress-strain specimens were exposed to the test temperature for 1/2 hour prior to loading. The rate of loading was controlled to achieve a nominal strain rate of 0.002 per minute in both the plate strength and material stress-strain tests.

COMPRESSIVE-STRENGTH RESULTS

Experimental Data

Experimental data from the plate strength tests for temperatures up to 600° F are presented in table I and in figure 3. In figure 3 the solid curves represent the variation of average stress with unit shortening obtained from the tests; the dashed curves indicate material compressive stress-strain curves.

The curves for the width-thickness ratio of 15 indicate that buckling and collapse occur at approximately the same stress. Similar results are indicated for $b/t = 20$ and 30. The plates for $b/t = 45$ and 60 buckle elastically at the lower test temperatures and possess some postbuckling strength. Above 350° F the postbuckling strength of plates with larger width-thickness ratios diminishes rapidly, and above 500° F the strength of this material deteriorates to such an extent that all plate sizes tested buckle in the plastic range of the material.

Estimation of Short-Time Plate Strength

If suitable material-properties parameters can be determined, the failing strength of plate-element structures can be correlated with changes in material properties. (See ref. 2.) An appropriate parameter for plate elements was defined in reference 2 as $(E_s\sigma_{cy})^{1/2}$, and a relation for correlating the maximum strength of plates with supported edges for all b/t ratios was expressed in the following form:

$$\frac{\bar{\sigma}_f}{\left(E_s\sigma_{cy}\right)^{1/2}} = f\left(\frac{t}{b}\right) \tag{1}$$

Satisfactory correlation with test data below $b/t = 60$ was obtained in reference 2 by using a linear expression for $f(t/b)$ in equation (1) as follows:

$$\frac{\bar{\sigma}_f}{\left(E_s\sigma_{cy}\right)^{1/2}} = 1.60\left(\frac{t}{b}\right) \tag{2}$$

In reference 4, equation (2) also yielded satisfactory estimates of maximum compressive strength for 2024-T3 aluminum-alloy plates at elevated temperatures. Similarly, in this investigation, equation (2) and the compressive stress-strain curves shown in figure 3 were used in obtaining calculated values of maximum strength. The calculated results are plotted as curves in figure 4 and are compared with test results shown by the symbols. The agreement between calculated and experimental results indicates the validity of equation (2) in estimating the strength of 7075-T6 aluminum alloy at elevated temperatures for the plate proportions tested.

PLATE CREEP RESULTS

Experimental Data

Typical unit-shortening results obtained during the plate creep tests are shown in figure 5 for temperatures ranging from 350° F to 500° F. The specimen number, applied stress $\bar{\sigma}$, and ratio of applied stress in the creep test to the maximum stress obtained from a strength test for 1/2-hour exposure $\bar{\sigma}/\bar{\sigma}_f$ are also given. A summary of all the creep test results is given in table II.

The creep behavior of 7075-T6 aluminum-alloy plates was similar to that of 2024-T3 aluminum-alloy plates described in reference 4; that is, buckles appeared gradually and continued to grow in depth along the entire length of the plate until the plate collapsed.

Estimation of Creep-Failure Stresses

Master creep lifetime curves.- The time-temperature parameter is often used in the analysis of material creep data and also has been found useful for presenting creep results for structural elements such as columns and plates. In figure 6, the applied stresses for all the creep tests of this investigation are correlated with the time-temperature parameter $T_R\left(C + \log_{10} \tau_f\right)$ (from ref. 9), where T_R is temperature in °R, C is a constant, and τ_f is failure time in hours. A value of C equal to 20 was found to be satisfactory for reducing the data to a single curve for each plate proportion. The solid curves represent average values of the test results, whereas the dashed curve indicates tensile rupture data for 7075-T6 aluminum alloy (from ref. 10) and is shown for comparison purposes.

When plate creep data are available, a plot of this type offers a convenient means for estimating creep-failure stresses at all temperatures and times within the range covered by the tests. In addition, by cross-plotting, creep-failure stresses for all b/t values within the range tested may be determined.

Isochronous compressive stress-strain curves.- When plate creep data are not available, it appears that the estimation of creep-failure stresses for any value of b/t can be accomplished in a manner analogous to the correlation of plate strength with material properties. For example, in reference 4, satisfactory estimates of creep-failure stresses for 2024-T3 aluminum-alloy plates were obtained with the aid of equation (2) and material creep data in the form of isochronous compressive stress-strain curves. In the present investigation, a study was made to determine whether this procedure could also be applied to 7075-T6 aluminum-alloy plates.

In order to obtain isochronous compressive stress-strain curves for 7075-T6 aluminum alloy, the initial portions of the creep curves given in figure 5(a) (where $b/t = 15$) were approximated by the following relation:

$$\epsilon = \frac{\sigma}{E_s} + A\tau^K \sinh \frac{\sigma}{\sigma_o} \qquad (3)$$

This relation was used so that the available creep curves could be extended over a complete range of stress, strain, and time. The first term on the right-hand side represents the strain achieved upon loading, as determined from the material stress-strain curve; the second term defines creep deformation. It was assumed that material creep data could be obtained from the creep curves for $b/t = 15$ because the plates for $b/t = 15$ remained flat or showed no evidence of buckles for a greater part of their lifetime than plates of larger proportions. The material creep constants A, K, and σ_o were evaluated from these curves and are listed in table III.

In figure 7, the calculated creep-failure stresses determined from equation (2) are shown as curves and are compared with experimental data shown by the symbols. In general, agreement between the experimental and calculated values is satisfactory.

Isochronous tensile stress-strain curves.- Tensile creep data are often used to predict creep behavior of different structural elements because compressive creep data are usually not available for most structural materials. For 7075-T6 aluminum alloy, the material compressive creep curves obtained in this investigation are significantly different from tensile creep curves obtained from a few tests conducted at temperatures corresponding to the plate creep tests. At a given stress and temperature, the tensile creep strains were generally greater than the compressive creep strains.

In order to determine whether the use of tensile creep data would be satisfactory for estimating creep-failure stresses for plates in compression, the creep test results from the present investigation were compared with calculated stresses obtained from isochronous tensile stress-strain curves and equation (2). The isochronous tensile stress-strain curves were based on the constants and relation given in reference 3. Calculated strains obtained with these constants were generally in good agreement with the strains obtained from the tensile creep tests. The calculated results for 400° F are compared with creep test results in figure 8. In general, the calculated results are not in good agreement with the test results. Since the tensile and compressive creep characteristics of this material are substantially different, disagreement would be expected. Disagreement between experimental and calculated results, similar to that shown in figure 8 for 400° F, was also found at the other temperatures investigated.

STRENGTH AND CREEP COMPARISONS OF 7075-T6 AND 2024-T3 ALUMINUM-ALLOY PLATES

The strength and creep results from the present investigation permit a direct comparison with similar results given in reference 4 for 2024-T3 aluminum-alloy plates. In figure 9, the maximum compressive strengths of 7075-T6 aluminum-alloy plates are compared with the maximum compressive strengths of 2024-T3 aluminum-alloy plates for a 1/2-hour exposure at elevated temperatures. The solid curves are calculated strength curves taken from figure 4 of this paper; the dashed curves are calculated strength curves from figure 5 of reference 4. The curves show a marked superiority in strength for 7075-T6 aluminum-alloy plates below 375° F. Above this temperature the compressive yield stress of 7075-T6 aluminum alloy decreases very rapidly, while the compressive yield stress of 2024-T3 aluminum alloy continues to increase as a result of artificial aging and reaches a maximum at 425° F for this exposure time. It should be noted that the temperature at which plates of the two materials possess the same strength (for equal values of b/t) will vary for different values of exposure time.

In making the comparison of creep-failure stresses for 7075-T6 and 2024-T3 aluminum-alloy plates, the temperatures for which plate creep data were available for both materials were confined to the narrow range from 400° F to 500° F. The plate creep-failure stresses for each material at 400° F are shown in figure 10. The solid curves are the calculated curves from figure 7; the dashed curves are the calculated curves from figure 19 of reference 4. The results show that 2024-T3 aluminum-alloy plates will support a given stress for a much longer time than 7075-T6 aluminum-alloy plates. Similar results were obtained at 450° F and 500° F. In view of the superior strength of 2024-T3 aluminum-alloy plates at these temperatures, results of this kind might be expected. It is possible that at lower temperatures for which plate creep data are not yet available for the two materials, 7075-T6 aluminum-alloy plates may be superior in creep.

CONCLUDING REMARKS

Experimental results from elevated-temperature strength and creep tests of 7075-T6 aluminum-alloy plates supported in V-groove edge fixtures have been presented and compared with calculated plate strengths and creep-failure stresses. The strength results indicate that a correlation procedure used for estimating plate compressive strength at room temperature is applicable for this material at elevated temperatures. Creep-failure stresses may also be calculated with this procedure if isochronous compressive stress-strain curves are substituted for the material stress-strain curve.

A comparison of the strength results for 7075-T6 and 2024-T3 aluminum-alloy plates indicates a superiority in strength for 7075-T6 aluminum-alloy plates up to approximately 375° F for a 1/2-hour exposure. For temperatures above 400° F, where plate creep data are available for both materials, a comparison of the results indicates that 2024-T3 aluminum-alloy plates will support a given stress for a longer time than 7075-T6 aluminum-alloy plates.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., June 8, 1957.

REFERENCES

1. Heimerl, George J., and Roberts, William M.: Determination of Plate Compressive Strengths at Elevated Temperatures. NACA Rep. 960, 1950. (Supersedes NACA TN 1806.)

2. Anderson, Roger A., and Anderson, Melvin S.: Correlation of Crippling Strength of Plate Structures With Material Properties. NACA TN 3600, 1956.

3. Mathauser, Eldon E., and Brooks, William A., Jr.: An Investigation of the Creep Lifetime of 75S-T6 Aluminum-Alloy Columns. NACA TN 3204, 1954.

4. Mathauser, Eldon E., and Deveikis, William D.: Investigation of the Compressive Strength and Creep Lifetime of 2024-T3 Aluminum-Alloy Plates at Elevated Temperatures. NACA Rep 1308, 1957. (Supersedes NACA TN 3552.)

5. Mathauser, Eldon E., and Deveikis, William D.: Investigation of the Compressive Strength and Creep Lifetime of 2024-T Aluminum-Alloy Skin-Stringer Panels at Elevated Temperatures. NACA TN 3647, 1956.

6. Shanley, F. R.: Weight-Strength Analysis of Aircraft Structures. McGraw-Hill Book Co., Inc., 1952, pp. 323-357.

7. Micks, W. R.: A Method for Determining the Effects of Elevated Temperature on Structural Design and Weight. Paper P-498, The RAND Corp., Mar. 1954.

8. King, C. W.: Creep Buckling of Integrally Stiffened Aluminum Alloy Panels. WADC Tech. Rep. 55-349. (North American Aviation, Inc. Contract AF 33(616)-2599, Project 1367), Wright Air Dev. Center, U. S. Air Force, May 1956.

9. Larson, F. R., and Miller, James: A Time-Temperature Relationship for Rupture and Creep Stresses. Trans. A.S.M.E., vol. 74, no. 5, July 1952, pp. 765-771; Discussion, pp. 771-775.

10. Dix, E. H., Jr.: Aluminum Alloys for Elevated Temperature Service. Aero. Eng. Rev., vol. 15, no. 1, Jan. 1956, pp. 40-48, 57.

TABLE I.- PLATE COMPRESSIVE-STRENGTH TEST

RESULTS FOR 1/2-HOUR EXPOSURE TIME

Plate	T, $^{\circ}F$	b/t	$\bar{\sigma}_f$, ksi	$\bar{\epsilon}_f$
1	Room	14.97	75.4	0.0108
2	Room	19.87	66.6	.0073
3	Room	29.74	46.9	.0048
4	Room	43.63	31.4	.0057
5	Room	60.48	23.0	.0055
6	300	15.64	60.3	.0107
7	300	20.29	52.6	.0062
8	300	30.18	38.8	.0043
9	300	43.69	26.2	.0045
10	300	60.46	20.2	.0057
11	350	14.99	53.7	.0102
12	350	20.03	47.4	.0069
13	350	29.81	36.6	.0043
14	350	43.70	24.2	.0051
15	350	60.41	17.5	.0042
16	400	14.90	40.8	.0087
17	400	19.86	38.9	.0066
18	400	30.58	29.2	.0039
19	400	44.18	21.2	.0046
20	400	59.85	15.0	.0042
21	450	15.22	28.4	.0104
22	450	20.07	26.6	.0057
23	450	30.28	21.6	.0039
24	450	43.56	16.7	.0026
25	450	60.47	13.2	.0032
26	500	15.12	20.0	.0102
27	500	19.88	18.8	.0056
28	500	30.34	16.3	.0037
29	500	44.76	12.9	.0020
30	500	60.48	10.5	.0025
31	600	14.84	12.1	.0119
32	600	20.15	11.6	.0058
33	600	29.69	10.6	.0045
34	600	43.26	8.4	.0021
35	600	60.67	6.2	.0015

TABLE II.- PLATE CREEP-TEST RESULTS[a]

Plate	T, °F	b/t	$\bar{\sigma}$, ksi	$\bar{\sigma}/\bar{\sigma}_f$	τ_f, hr
36	350	14.85	49.0	0.913	0.54
37	350	15.61	47.0	.875	1.56
38	350	15.73	44.6	.830	2.30
39	350	15.58	42.0	.782	5.31
40	350	14.87	40.0	.745	11.02
41	350	20.09	38.0	.802	1.58
42	350	20.09	32.5	.685	9.30
43	350	29.62	28.0	.765	1.65
44	350	29.88	25.0	.683	9.91
45	350	43.95	20.8	.858	3.09
46	350	44.51	20.0	.827	3.99
47	350	43.75	19.0	.785	8.88
48	350	59.76	16.8	.960	1.56
49	350	59.75	16.0	.914	5.15
50	400	14.95	34.4	.843	1.78
51	400	15.60	33.0	.809	2.06
52	400	14.95	31.9	.782	2.71
53	400	15.56	31.0	.760	4.18
54	400	15.71	29.0	.711	6.71
55	400	15.94	22.5	.551	[b]13.00
56	400	19.81	29.5	.758	.82
57	400	20.42	22.5	.578	12.75
58	400	30.10	22.5	.771	.90
59	400	29.86	17.5	.599	6.19
60	400	44.58	16.0	.755	1.78
61	400	44.02	13.8	.648	7.60
62	400	60.80	12.4	.827	1.81
63	400	59.67	11.0	.733	6.85
64	450	15.07	24.0	.845	1.17
65	450	15.11	23.0	.810	1.50
66	450	15.04	21.0	.740	2.70
67	450	14.94	19.0	.669	8.50
68	450	14.96	16.0	.563	17.87

[a]All plates were exposed for 1/2 hour at test temperature prior to loading.

[b]Test stopped before failure.

TABLE II.- PLATE CREEP TEST RESULTS - Concluded

Plate	T, °F	b/t	$\bar{\sigma}$, ksi	$\bar{\sigma}/\bar{\sigma}_f$	τ_f, hr
69	450	20.13	21.2	0.800	1.34
70	450	20.11	20.2	.757	1.92
71	450	20.14	18.8	.707	2.68
72	450	20.20	16.3	.613	8.00
73	450	20.14	15.2	.572	15.64
74	450	20.32	13.5	.507	26.38
75	450	29.78	16.8	.778	1.02
76	450	29.59	13.3	.616	5.45
77	450	44.71	12.5	.748	.69
78	450	44.78	9.7	.581	8.22
79	450	60.51	10.8	.818	.47
80	450	59.67	10.2	.773	.88
81	450	60.01	8.7	.659	2.39
82	450	59.85	7.0	.530	14.18
83	500	15.08	16.5	.825	.92
84	500	15.09	15.5	.775	3.20
85	500	15.04	14.0	.700	6.67
86	500	15.12	13.3	.665	8.12
87	500	15.02	12.5	.625	16.50
88	500	20.07	15.0	.798	1.28
89	500	20.56	14.0	.745	1.18
90	500	20.37	11.7	.622	5.98
91	500	29.77	12.5	.767	1.54
92	500	29.52	10.0	.613	5.72
93	500	43.68	11.0	.852	.48
94	500	43.55	10.0	.775	1.31
95	500	44.58	7.0	.542	11.40
96	500	59.76	7.0	.667	1.74
97	500	59.66	5.0	.476	14.30

TABLE III.- COMPRESSIVE MATERIAL CREEP CONSTANTS FOR THE CREEP RELATION $\epsilon = \frac{\sigma}{E_s} + A\tau^K \sinh \frac{\sigma}{\sigma_o}$ FOR 7075-T6 ALUMINUM ALLOY

[σ and E_s in ksi; τ in hours]

T, °F	A	σ_o	K
350	2.00×10^{-4}	13.00	0.304
400	1.07	8.00	.470
450	.728	4.88	.549
500	.252	2.64	.573

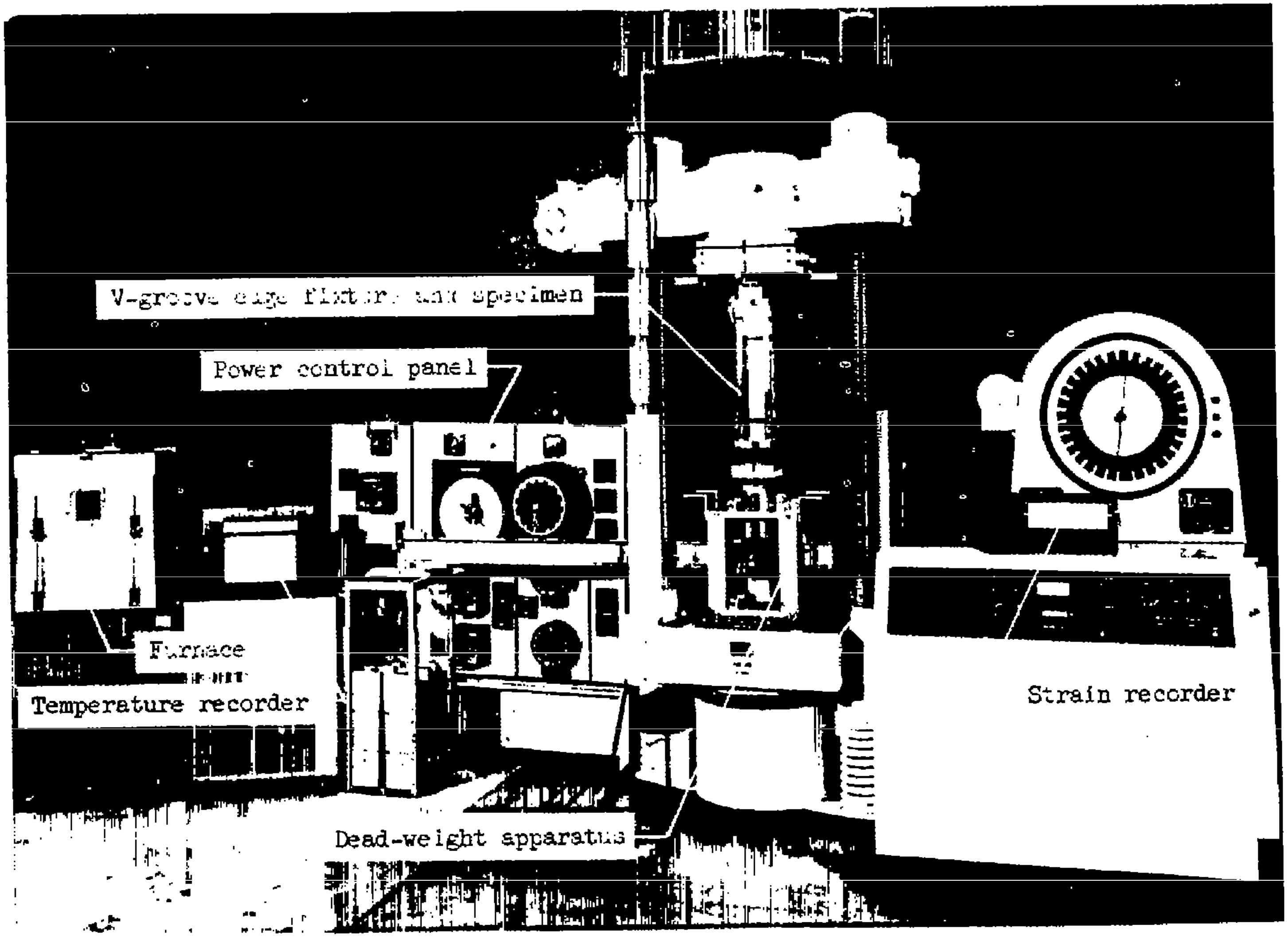


Figure 1.- Testing and recording equipment. L-90001.3

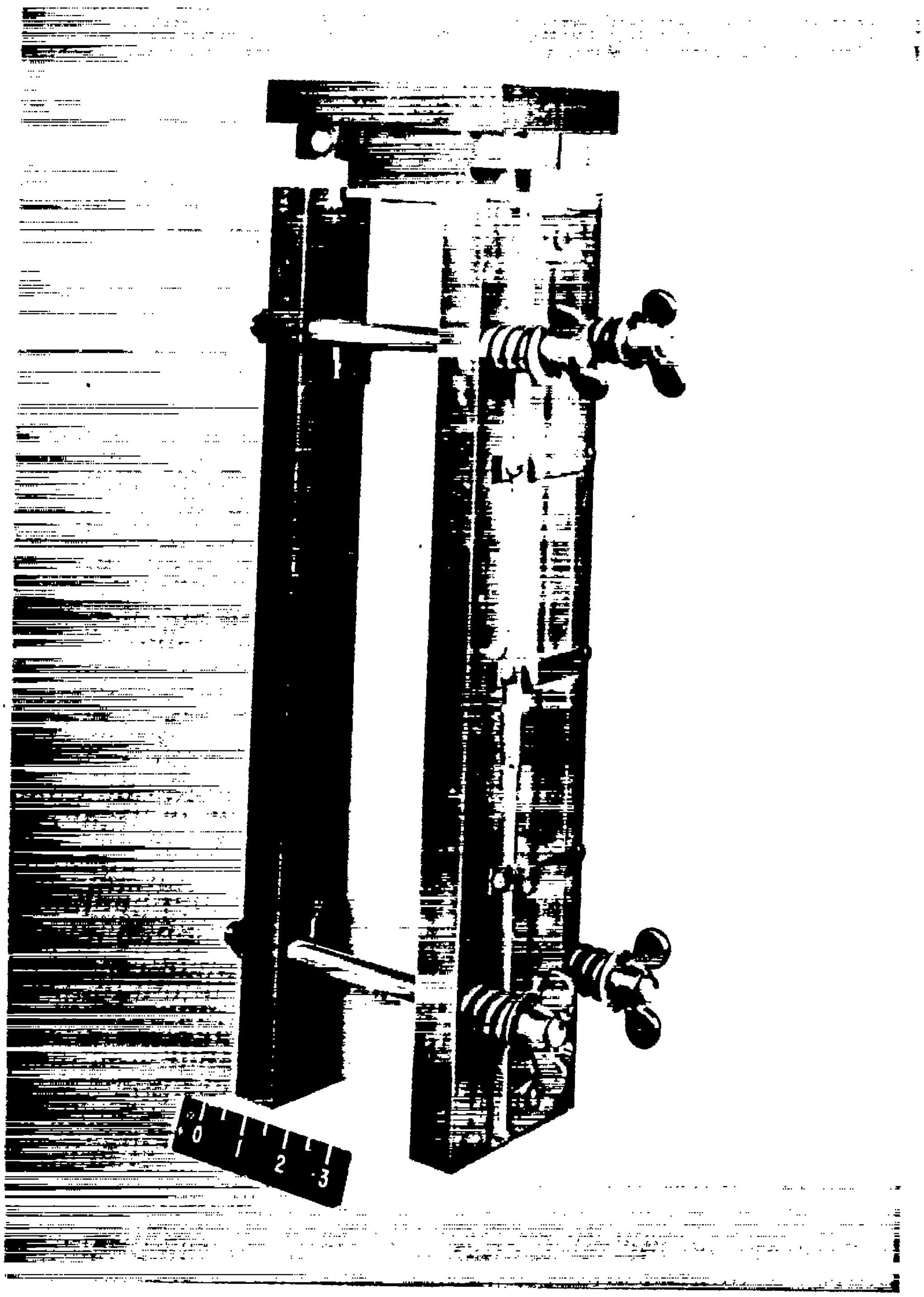


Figure 2.- Plate specimen in V-groove edge fixture.   L-90005

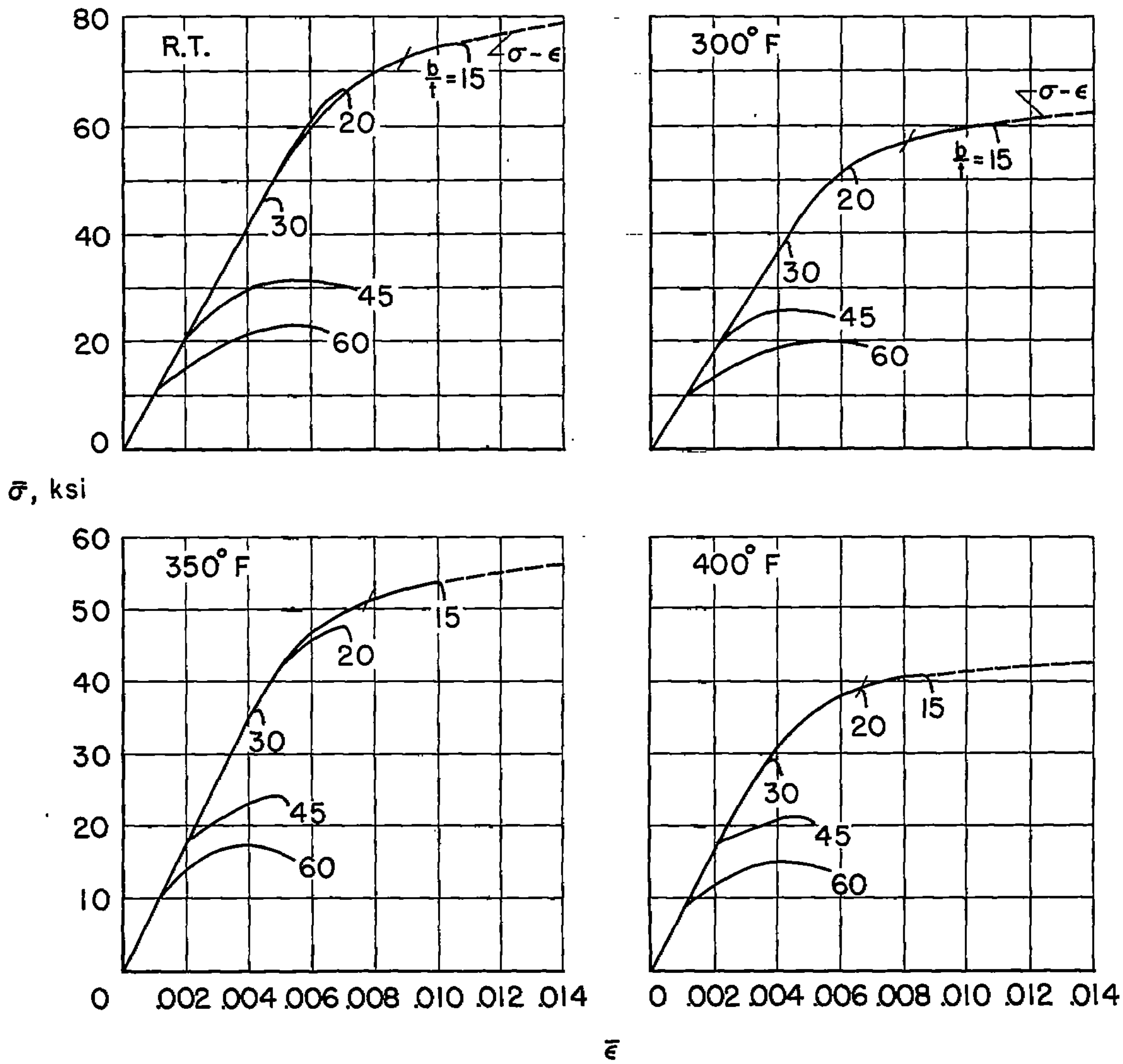


Figure 3.- Average stress plotted against unit shortening for 7075-T6 aluminum-alloy plates.

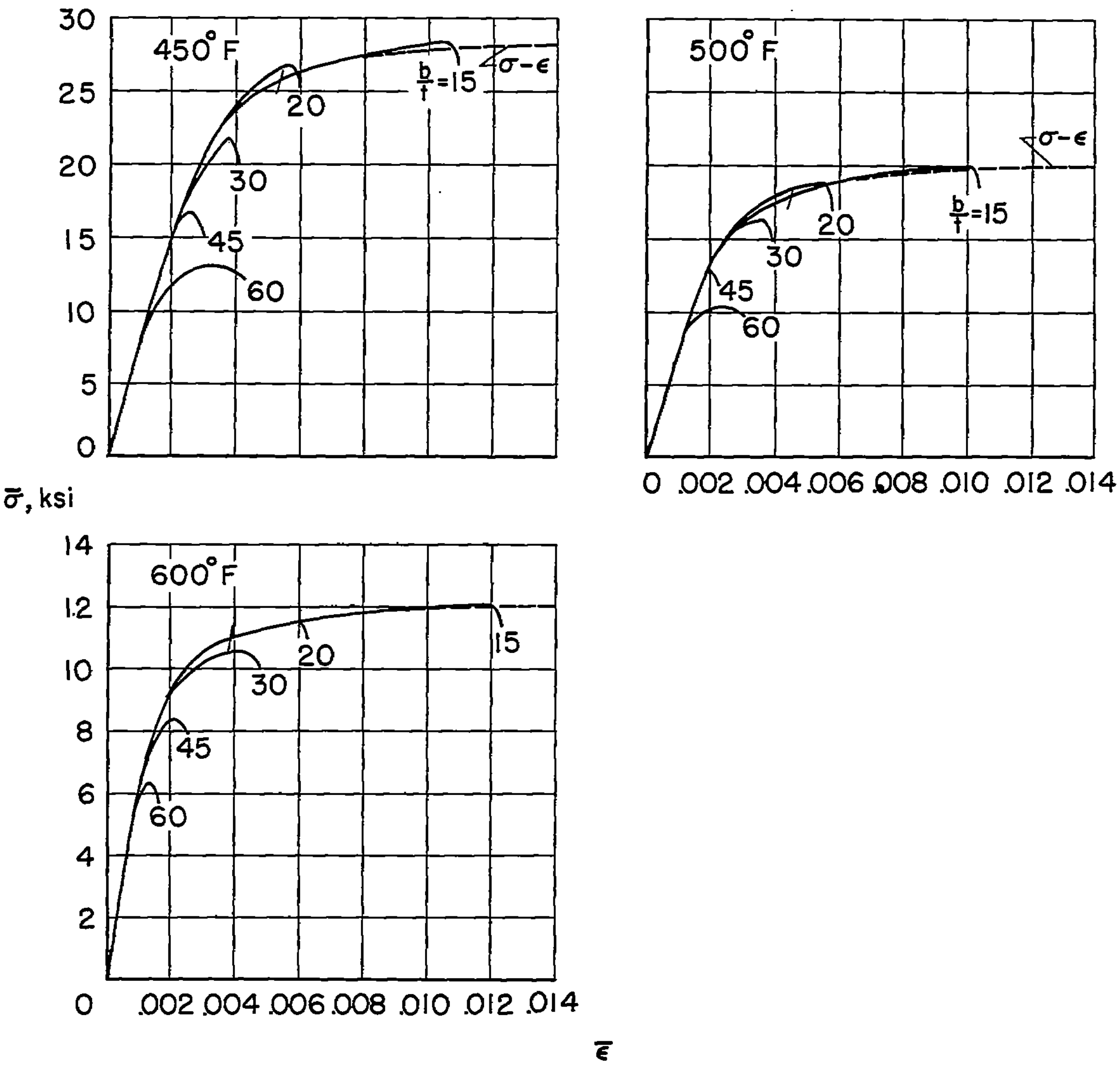


Figure 3.- Concluded.

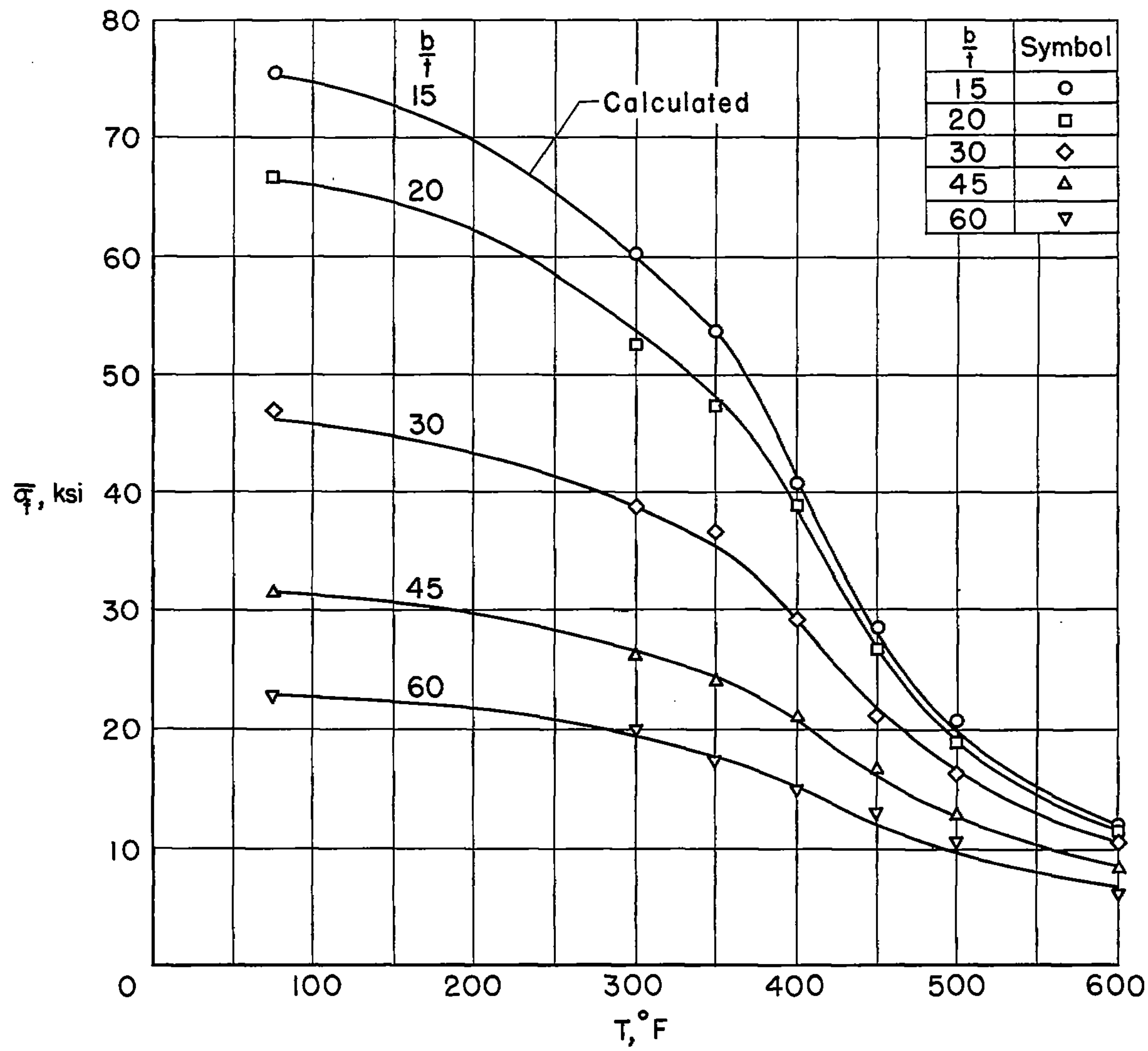
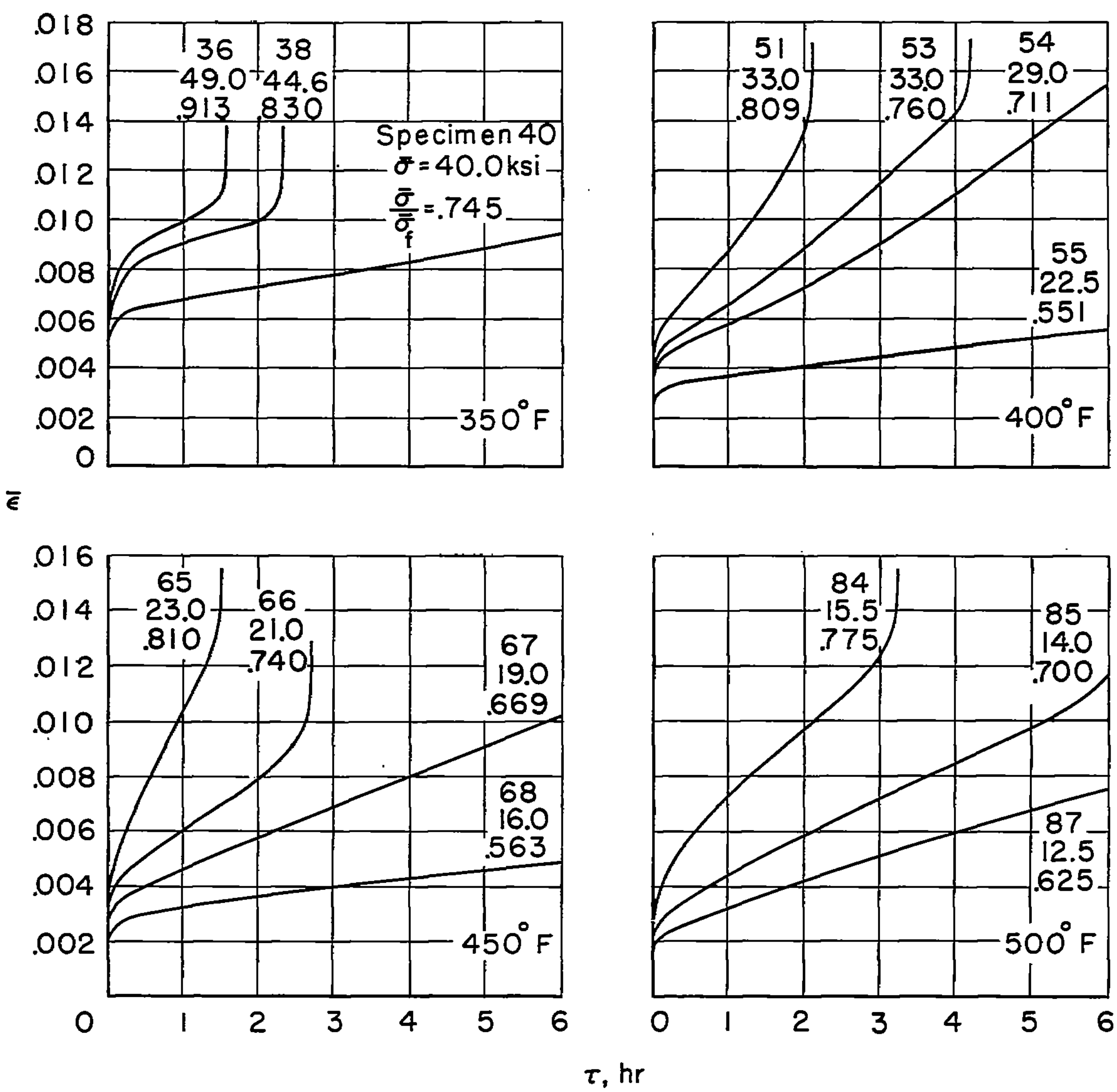
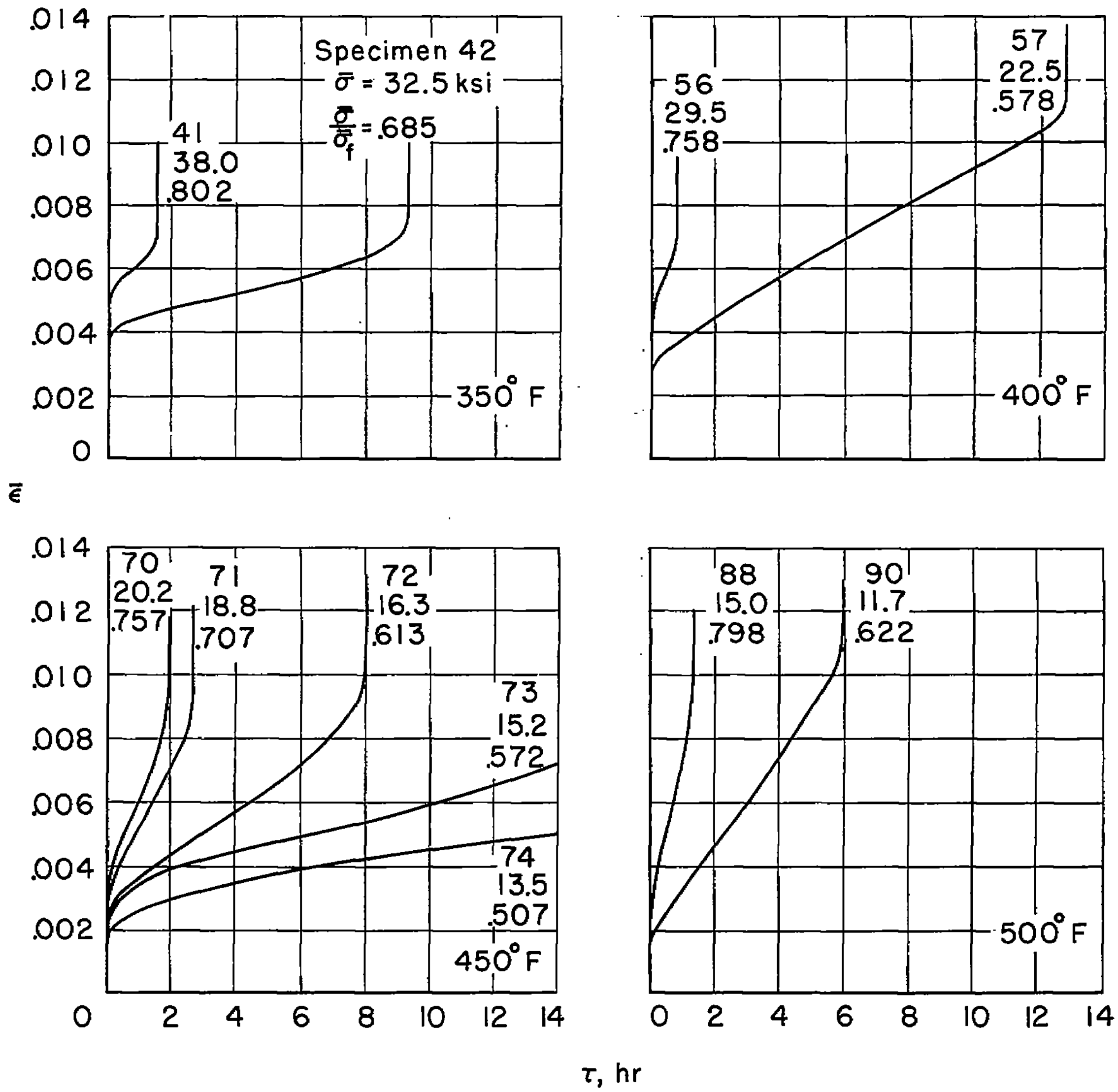


Figure 4.- Comparison of experimental and calculated compressive-strength results for 7075-T6 aluminum-alloy plates after a $\frac{1}{2}$-hour exposure at elevated temperatures.



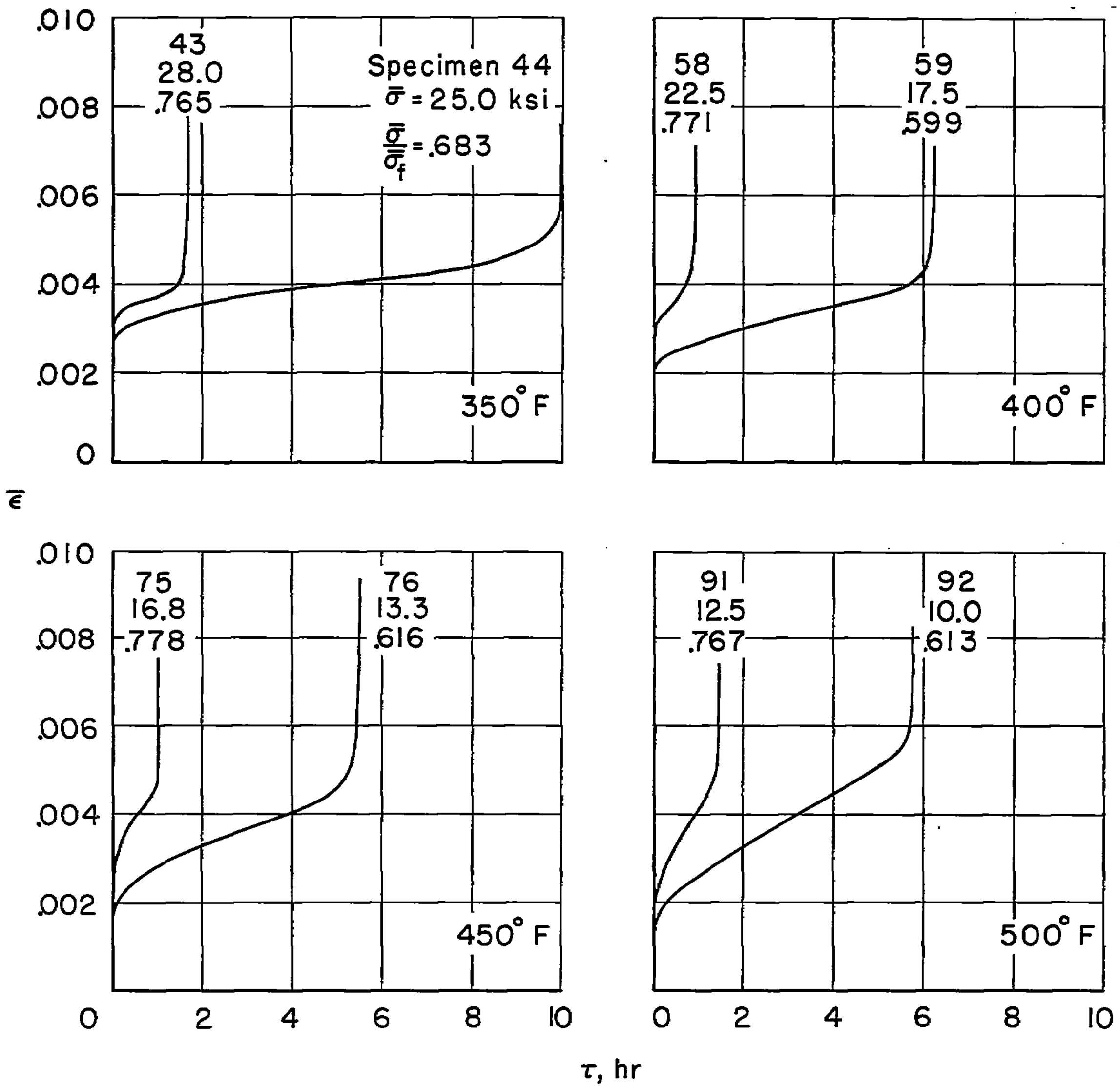
(a) $\frac{b}{t} = 15$.

Figure 5.- Creep curves for 7075-T6 aluminum-alloy plates.



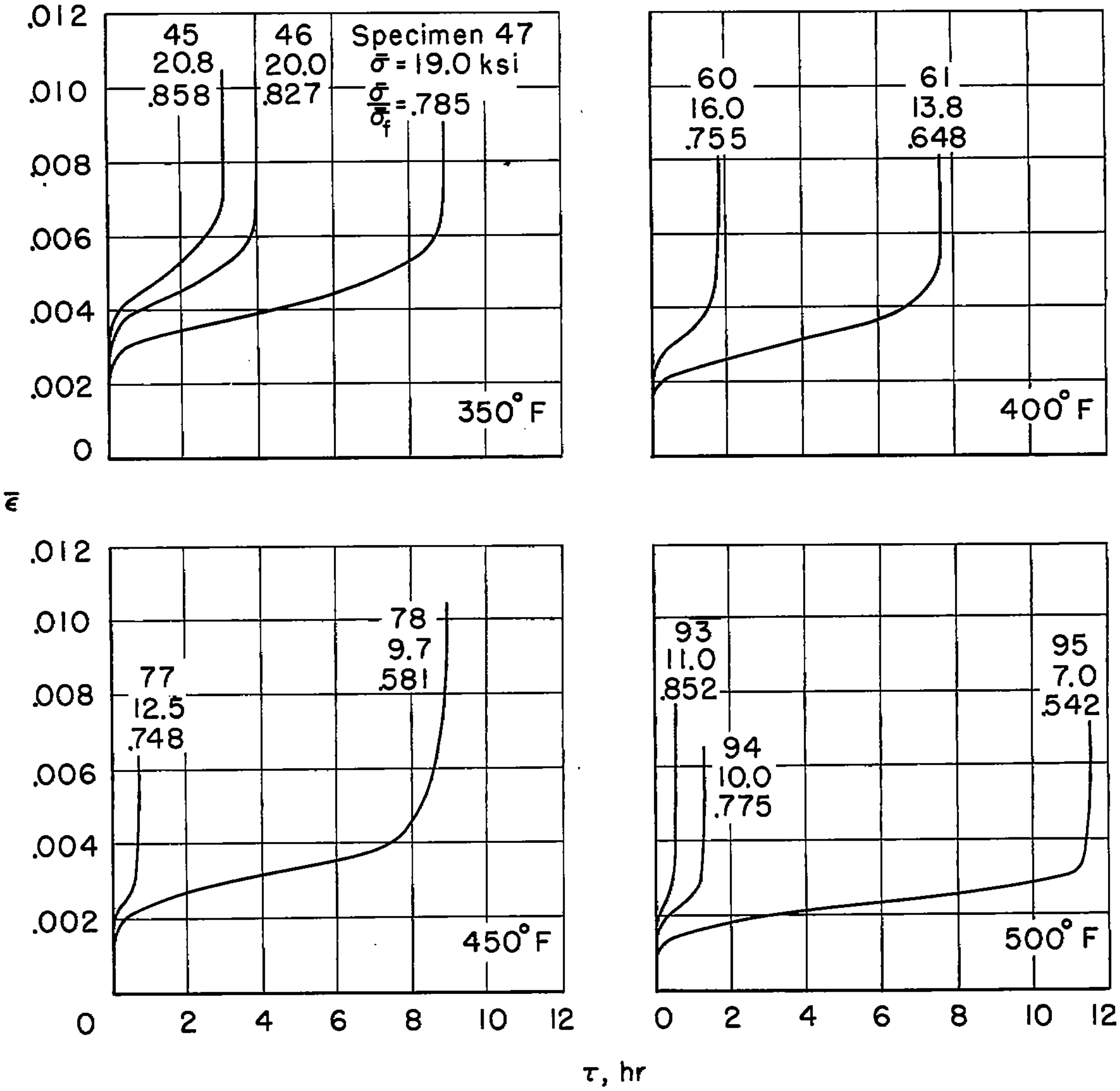
(b) $\frac{b}{t} = 20$.

Figure 5.- Continued.



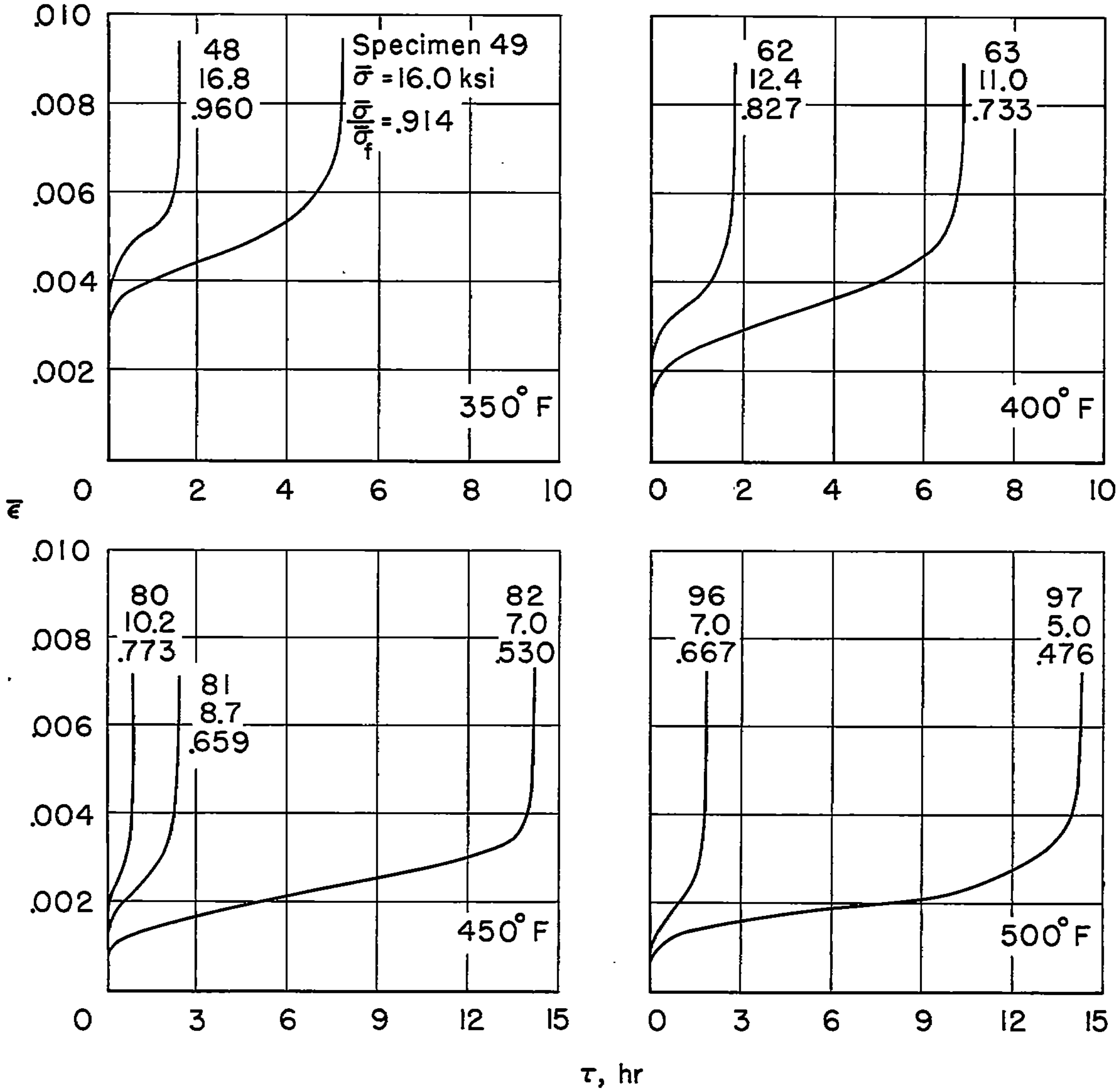
(c) $\frac{b}{t} = 30$.

Figure 5.- Continued.



(d) $\frac{b}{t} = 45.$

Figure 5.- Continued.



(e) $\frac{b}{t} = 60$.

Figure 5.- Concluded.

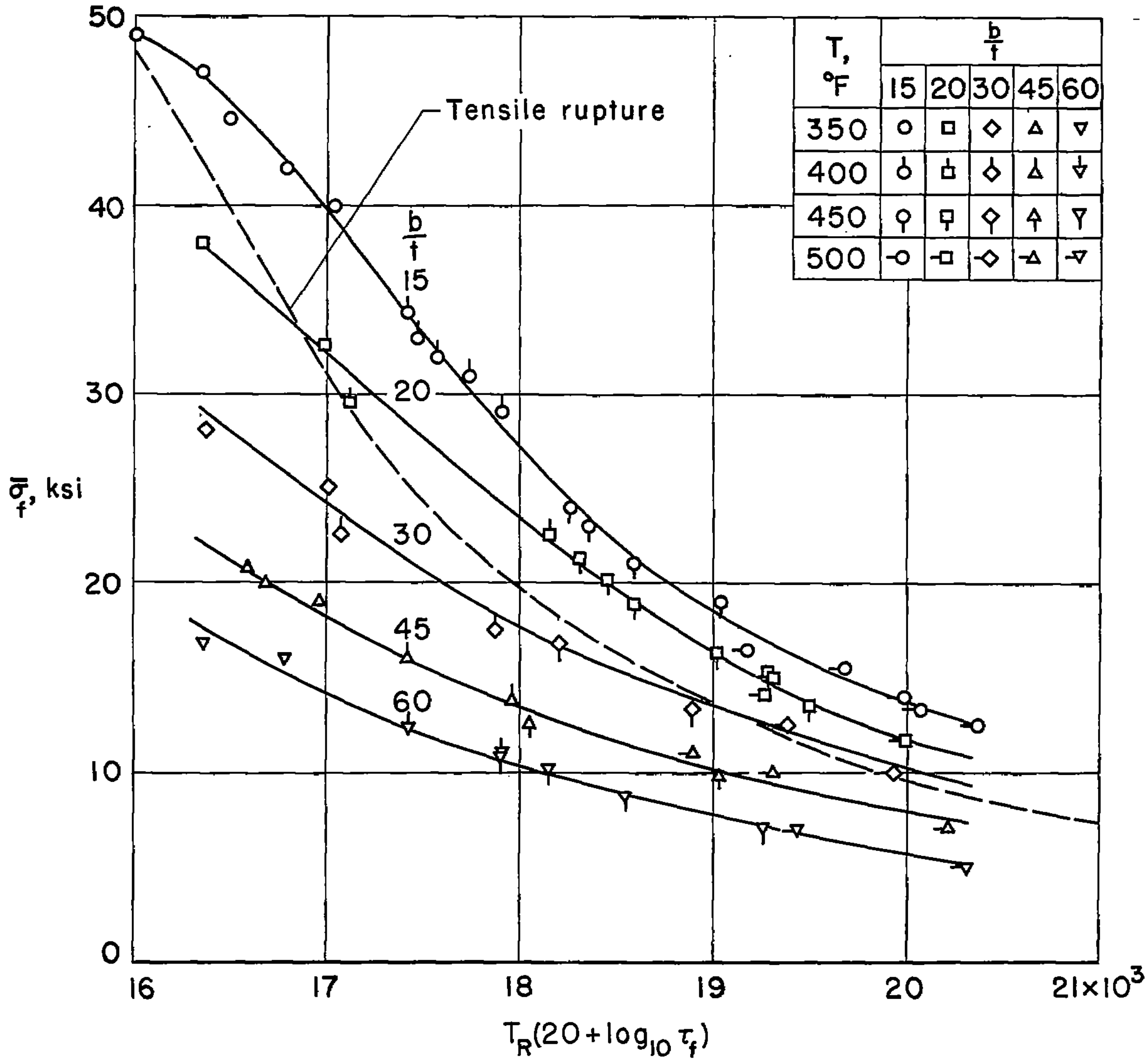


Figure 6.- Master creep-lifetime curves for 7075-T6 aluminum-alloy plates.

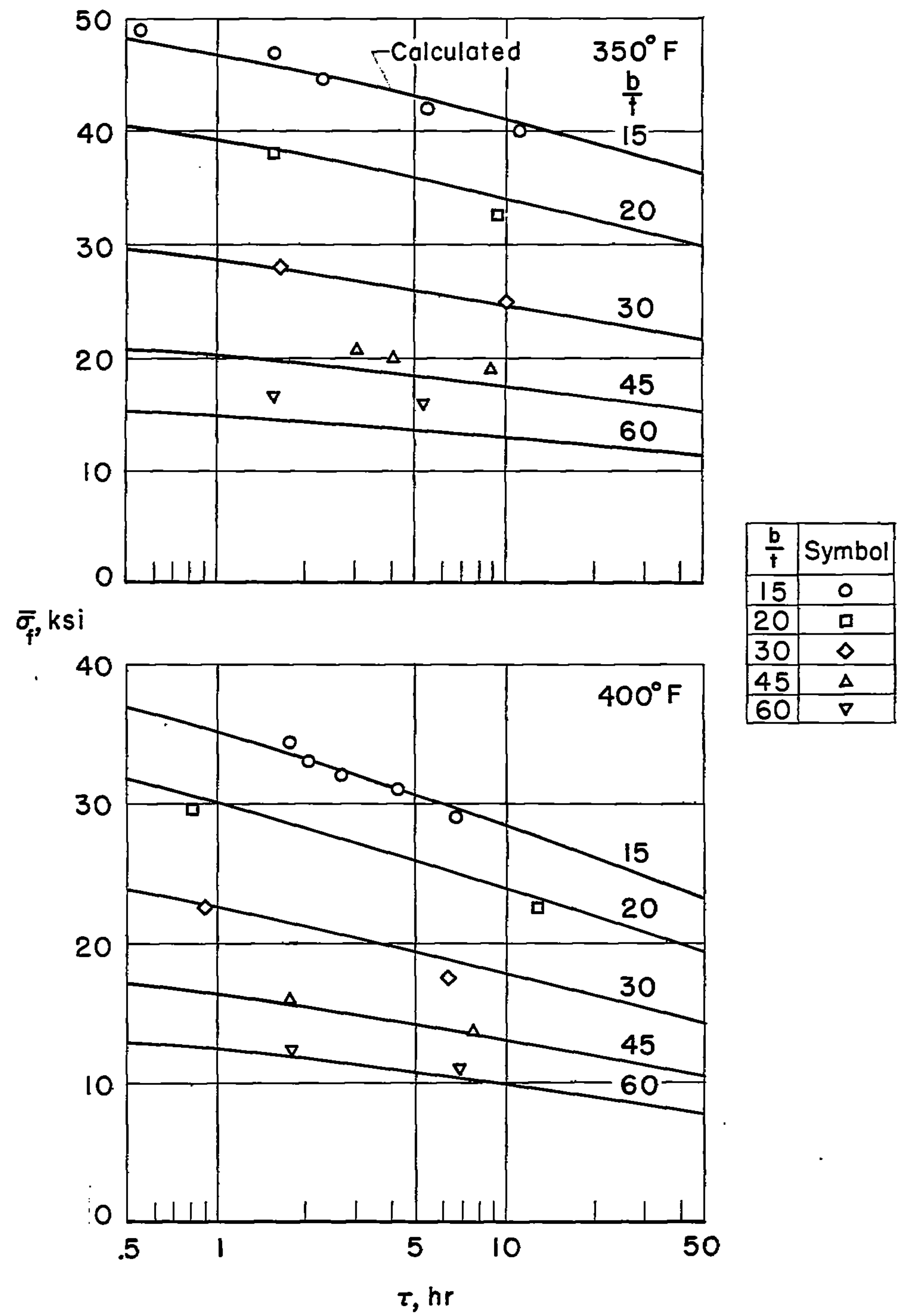
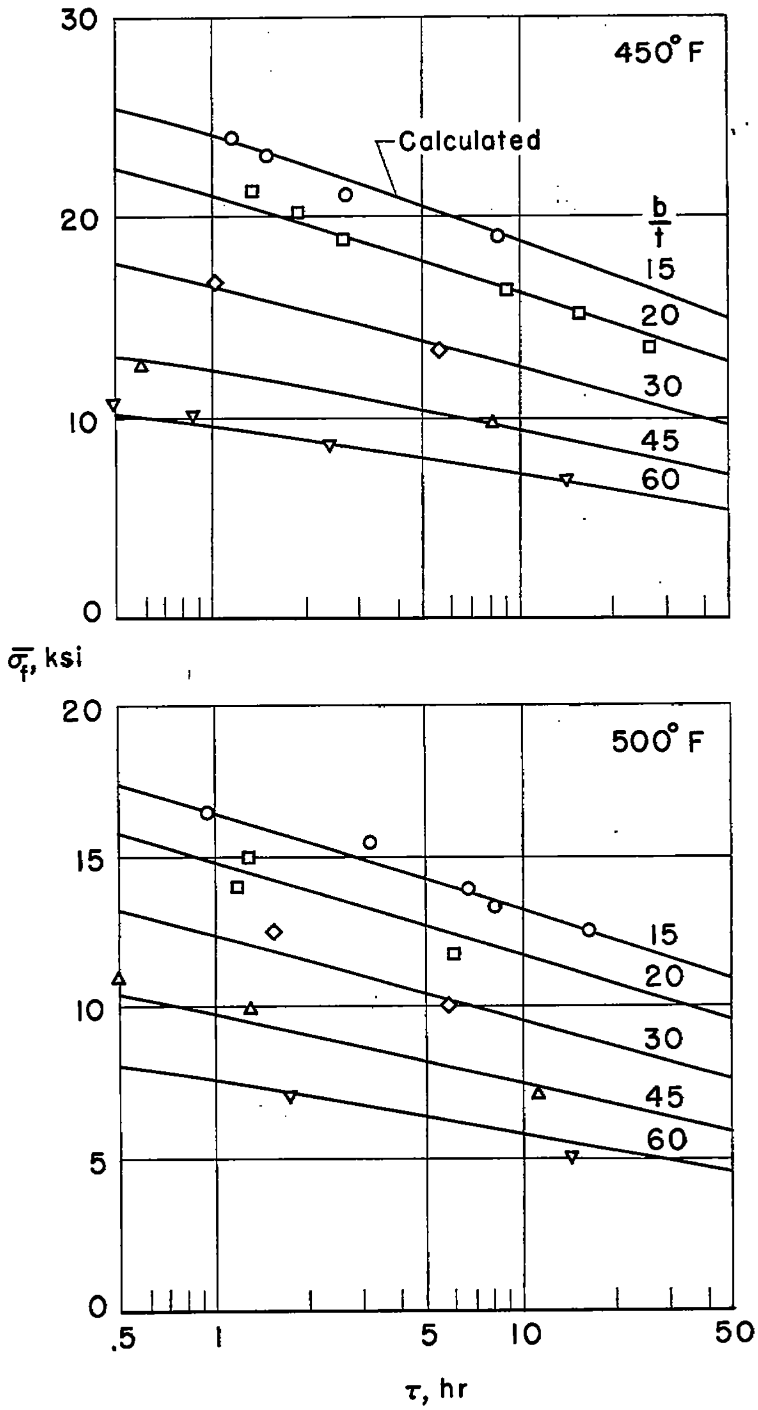


Figure 7.- Comparison of experimental and calculated creep-failure stresses.



$\frac{b}{t}$	Symbol
15	○
20	□
30	◇
45	△
60	▽

Figure 7.- Concluded.

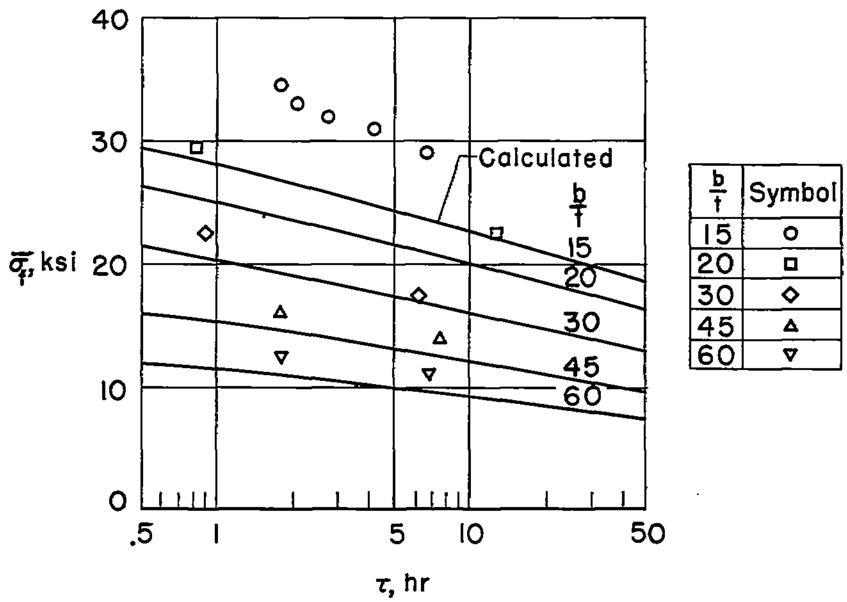


Figure 8.- Comparison of experimental data and calculated creep-failure stresses obtained from tensile creep data and equation (2) at 400° F.

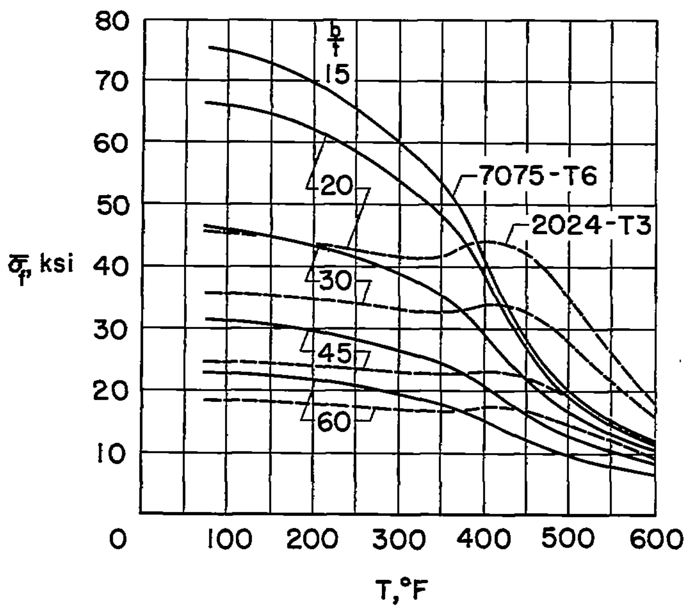


Figure 9.- Comparison of maximum compressive strengths of 7075-T6 and 2024-T3 aluminum-alloy plates after a $\frac{1}{2}$-hour exposure.

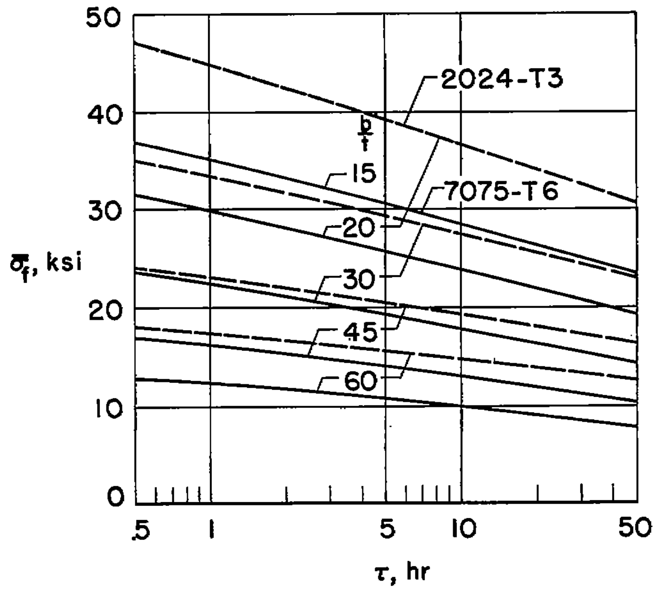


Figure 10.- Comparison of creep-failure stresses of 7075-T6 and 2024-T3 aluminum-alloy plates at 400° F.